Federal Aviation Administration

DOT/FAA/AM-05/19
Office of Aerospace Medicine
Washington, DC 20591

# Terminal Radar Approach Control: Measures of Voice Communications System Performance

O. Veronika Prinzo
Mark McClellan
Civil Aerospace Medical Institute
Federal Aviation Administration
Oklahoma City, OK 73125

October 2005

Final Report

# NOTICE

**Technical Report Documentation Page**

| 1. Report No. DOT/FAA/AM-05/19 | 2. Government Accession No. | 3. Recipient's Catalog No. |
|---|---|---|
| 4. Title and Subtitle Terminal Radar Approach Control: Measures of Voice Communications System Performance | | 5. Report Date October 2005 |
| | | 6. Performing Organization Code |
| 7. Author(s) Prinzo OV, McClellan M | | 8. Performing Organization Report No. |
| 9. Performing Organization Name and Address FAA Civil Aerospace Medical Institute P.O. Box 25082 Oklahoma City, OK 73125 | | 10. Work Unit No. (TRAIS) |
| | | 11. Contract or Grant No. |
| 12. Sponsoring Agency name and Address Office of Aerospace Medicine Federal Aviation Administration 800 Independence Ave., S.W. Washington, D.C. 20591 | | 13. Type of Report and Period Covered |
| | | 14. Sponsoring Agency Code |
| 15. Supplemental Notes This work was performed under Task AM-B-03-HRR-516. | | |

16. Abstract:
Effective communications in the National Airspace System (NAS) is an essential safety component of successful air travel. As the NAS migrates from its current ground infrastructure and voice communications system to one that encompasses both ground and airborne systems, digital data transmission may become the principal communication medium. As technological advances lead to innovations in communications system development, these emerging systems will be evaluated against the existing legacy system's performance parameters such as setup delay, voice streaming, pause duration, and message propagation. The data presented here are but a first step in providing objective and quantifiable communications system performance metrics that may prove valuable to communication systems developers and personnel charged with evaluating, certifying, and deploying the next generation of communications systems. The authors analyzed nearly 8,000 transmissions that represented the busiest air-ground communications from the five terminal radar approach control facilities with the highest number of operations in the contiguous United States. Typically, setup delays lasted 81 ms, voice streaming 2568 ms, pause duration 127 ms, and message propagation 73 ms for a total of 2849 ms per transmission. On average, transmissions were separated by 1736 ms of silence. Disruptions to efficient information transfer can result from blocked, stepped-on, and clipped transmissions — but they are rare events and occurred in only 1.16% of the sampled transmissions. A comparison between aircraft with and without disruptions revealed that when a disruption was present, an average of 14.54 messages were transmitted, compared with an average of 9.90 messages when no disruption was present. Even so, there appears to be some type of a detection mechanism in place to alert the controller to the presence of blocked transmissions. The source is of this detection system is unclear; however, systems developers may want to exploit and expand this capability to include stepped-on and clipped transmissions.

| 17. Key Words | 18. Distribution Statement |
|---|---|
| Communications, ATC Communication, Air Traffic Control | Document is available to the public through the Defense Technical Information Center, Ft. Belvior, VA 22060; and the National Technical Information Service, Springfield, VA 22161 |

| 19. Security Classif. (of this report) | 20. Security Classif. (of this page) | 21. No. of Pages | 22. Price |
|---|---|---|---|
| Unclassified | Unclassified | 23 | |

**Form DOT F 1700.7** (8-72) Reproduction of completed page authorized

# Terminal Radar Approach Control: Measures of Voice Communications System Performance

*Societies have always been shaped more by the nature of the media by which men communicate than by the content of the communication.*

— Marshall McLuhan
Canadian communications and media theorist and Quentin Fiore
*The Medium Is the Massage*, Random House (1967)

According to a 2004 report issued by the Federal Aviation Administration (FAA) Office of Aviation Policy and Plans (FAA, 2004), there were more than 120 million aircraft operations recorded in 2003. That report projected that the total civil aircraft activity will reach in excess of 137 millions operations by 2015 and nearly 162 million by 2030. In response to the anticipated growth in aircraft activity, the FAA's efforts have been directed at ensuring that sufficient system capacity will be available to support these traffic projections. In addition to increasing the number of runways at airports, the FAA will develop programs, procedures, and technologies to enable more efficient use of the airspace. Likewise, as the demand for air traffic services increase, there will be a corresponding increase in air traffic communications and voice radio frequency congestion. In anticipation, the FAA plans a transition from its current analog voice communications system towards a new, state-of-the-art, next generation voice- and data-based communications system.

As the National Airspace System migrates from its current ground infrastructure and analog voice communications system to one that encompasses both ground and airborne systems, digital data transmissions will be the principal communication medium. Unlike the voice-mode currently used in the analog voice domain, the future system may rely upon digital voice transmission techniques (National Airspace System Capital Investment Plan, 2005). The FAA envisions that data-linked communications (e.g., VHF Digital Link Mode 3) will provide route-of-flight clearances, airport information, aircraft position both on airport surfaces and in the air, weather conditions, and other information to data-link-equipped aircraft. However, voice communications will still be available to pilots flying unequipped aircraft and will operate as a back-up system in the event of an individual unit or system failure.

The FAA's Mission Need Statement 137 (MNS 137, 1995a) and the subsequent NEXCOM Investment Analysis Report (1998) describe shortfalls in the frequency spectrum capacity of the current Air/Ground (A/G) communications system. For example, demand is expected to grow at an annual rate of 4% for new A/G communication voice frequency assignments (especially for already congested terminal and surrounding airspace) and for frequencies to support a variety of new A/G communications services in the limited very high frequency (VHF) band. Therefore, this level of growth cannot be accommodated by the current analog system. Other needs called out in MNS 137 include a reduction in logistical costs for maintaining radios, introduction of new data link capability, a reduction in radio frequency interference (RFI), and improved security against threats such as "phantom controllers."

In response to these needs, the NEXCOM Investment Analysis identified a segmented program for upgrade and replacement of the present air traffic control (ATC) A/G communications string. The NEXCOM Requirements Document (RD) also identified a number of operational and technical constraints that must be accommodated while satisfying these requirements. Specifically, a fundamental requirement of NEXCOM Segment 1 was to provide additional voice channels with no disruption of the present voice service. Furthermore, NEXCOM was to achieve this increased capacity with minimum disruption of the present VHF A/G communications physical system configuration. Finally, NEXCOM sought after a seamless evolution from the present analog double side-band-amplitude modulation (DSB-AM) A/G system to a new digital communications functional capability.

Investigations performed by the NEXCOM Product Team of the voice communication literature revealed that the existing operational communications databases do not provide current information concerning the frequency of occurrence or the severity of stepped-on or blocked transmissions. This information is critical for an analysis of the operational and safety benefits that justify an investment in the development of any proposed communications systems. For instance, previous simulation studies demonstrated that the number of blocked transmissions increases both as the number of communications increases and with the amount of ground-air transmission delay (Nadler et al., 1993; Sollenberger, McAnulty, & Kerns, 2003). These delays consist of two components: setup and propagation. Optimally, before delivering a message,

the sender depresses the push to talk (PTT) switch, waits until the setup delay elapses,[1] and then begins speaking. The failure to wait until the setup time elapses may result in the initial portion of the voice stream not being transmitted, or "clipped."

The propagation component of a transmission is the transit time for the voice signal to travel from its source to its destination. The propagation component that was measured consisted of the time that a transmitted signal was present in the sector of sufficient strength to block other similar transmissions. Once the PTT switch is released, the communications channel is open to either receive or send another message.[2] If the intended recipient of the message happens to depress the PTT switch during the propagation component, the message-in-transit may be blocked. A blocked transmission is a radio transmission that has been distorted or interrupted due to the presence of multiple simultaneous radio transmissions such that they could cancel each other out. There is a widespread belief that such blocked transmissions are always detected (i.e., heterodyne heard);[3] however, both messages could be completely lost (O'Neil, 2005).

"Stepped-on" transmissions, like blocked transmissions, occur when there are two simultaneous transmissions; however, rather than canceling each other out, two different outcomes exist. In the first case, the stronger signal in one transmission may override the weaker signal causing it (i.e., the weaker signal) not to be heard. Alternatively, the stronger signal from a part of one message may be appended to a message from a different speaker, thereby creating a complete, albeit erroneous, transmission. Consequently, the initiation of a transmission on an occupied frequency can result in vital information not being received by the intended air traffic controller or pilot. Both clipped and stepped-on messages often require additional transmissions – either in the form of a repeat, a request for a repeat, or to provide clarification to the intended recipient.

Unfortunately, the existing data on controller-pilot operational communications were collected 8-10 years ago and may not constitute a valid basis for comparison with, or extrapolation to, the expected communications environment operating in 2010. Therefore, data on the current operational communications system are needed to establish a baseline against which the future communications system's performance can be compared. Operational voice communications from the busiest terminal radar approach control (TRACON) facilities were obtained, transcribed, and analyzed.

## METHOD

This report presents compelling baseline analog voice communications system performance data that can be used to benchmark future systems. The data include duration parameters (e.g., setup delay, voice-streaming time, pause duration following voice offset, message propagation, frequency occupancy time, and lag time between successive transmissions) and the prevalence of disruptions to efficient information transfer (e.g., blocked, stepped-on, and clipped transmissions). The measures of voice communications system performance were derived from 10 hr of communications-intensive operations — four 15 min samples of arrival and four 15 min samples of departure operations from each of the five busiest TRACON facilities in the United States.

### Materials

**Audio Tapes.** Five of America's busiest Terminal Radar Approach Control (TRACON) facilities provided 5 hr of approach and 5 hr of departure control voice communications on digital audiotapes (DAT) for a total of 10 hr of communications per facility. DAT recordings were made using the NiceLogger™ Digital Voice Recorder System (DVRS) to record and time-stamp each transmission. They included both voice communications data and PTT actions. Each DAT contained separate voice records of all communications transmitted on the radio frequency assigned to a particular sector position on the left channel. The right channel contained the Universal Time Coordinated (UTC) time code expressed in date, hour (hr), minute (min), and whole second (s). The NiceLogger™ Digital Voice Reproducer System (DVRS) decoded and displayed time and correlated it with the voice stream in real time.

**Audio Software.** Adobe Audition™ (1.5), a software tool for audio editing, was used to extract voice and PTT onset and offset times. We used it to record, convert, and save the data as digital audio files for subsequent analysis. Audio data was displayed in either a waveform or spectral view. In the waveform view, the horizontal axis represented time, and the vertical axis represented the amplitude as a

---

[1]FAA (1995 b). NAS-SS-1000 Volume III states that a VHF/UHF communications outlet receiver/transceiver shall establish a carrier for radio frequency signals within 35 ms after the transmitter enable signal enters the VHF/UHF communications outlet transmitter/transceiver.

[2]FAA (1995b). NAS-SS-1000 Volume III states that a VHF/UHF communications outlet receiver/transceiver shall remove the carrier for radio frequency signals within 35 ms after the transmitter disable signal enters the VHF/UHF communications outlet.

[3]Heterodyning is the production of a beat note at a frequency given by the difference in frequency of two interfering signals.

series of spikes. In the spectral view, the audio signal was displayed by its frequency components. The horizontal axis again represented time, but the vertical axis measured frequency and displayed the amplitude in an array of colors ranging from dark blue (low amplitude) to bright yellow (high amplitude).

### Selection of Data Samples

Audiocassette tapes were dubbed from each DAT for the transcribers to use to create verbatim transcripts. Each message was typed onto an electronic copy of the Aviation Topic Speech Act Taxonomy-Coding Form (Prinzo, Britton, & Hendrix, 1995), along with its onset and offset time. Transmissions were divided into 15 min samples according to sector and TRACON facility. For each TRACON facility, the results of a frequency analysis identified four 15 min approach and four 15 min departure samples that contained the most pilot-controller transmissions. They were selected for waveform analysis. Table 1 shows that the subsequent database consisted of approximately 10 hr of pilot-controller transmissions — 1 hr of approach and 1 hr of departure transmissions for each facility.

### Subject Matter Experts (SMEs)

The air traffic SME was an instrument-rated pilot and former controller who had worked as an FAA Academy instructor for 8 years and had worked for 12 years in FAA supervision and management. He had an Airline Transport Pilot rating and was completing a Masters Degree in electrical engineering. The first author, serving as the third SME, had 12 years of experience analyzing pilot controller communications.

### Tape Analysis Procedures

Prior to transferring the audiocassette tape recording to the computer, the PC soundcard was adjusted using Record Control (In Line Volume) to record the bulk of data between ± 75% of scale, with no peaks outside ± 80%. This established the maximum dynamic range to retain small signal details. To maintain consistency in data recording, all dubbing took place at the same workstation and tape deck. The third SME dubbed all of the DVR recordings onto analog cassette tapes that were then recorded onto the computer-workstation using Adobe Audition for subsequent analysis.

### Extraction of Voice Communications Data Points

The voice communications system performance duration measures were computed from the data points that were identified by listening to and inspecting individual waveforms of pilot and controller transmissions. The analysis points represented the time displayed in Adobe Audition at a zero crossing. They included push-to-talk onset, voice onset, voice offset, push-to-talk release, and push-to-talk settle. They are presented in the logical

**Table 1.** Number and Duration of Transmissions

| | Number of Transmissions | | | |
|---|---|---|---|---|
| **Source** | **Pilot/Controller** | **Land-line** | **Total** | **Duration** |
| Approach | | | | |
| Atlanta | 816 | 28 | 844 | 1 hr 02 min 04 s |
| Chicago | 908 | 46 | 954 | 0 hr 59 min 49 s |
| Dallas Ft Worth | 774 | 35 | 809 | 1 hr 00 min 02 s |
| New York | 1355 | 32 | 1387 | 1 hr 00 min 01 s |
| Southern California | 631 | 16 | 647 | 1 hr 00 min 28 s |
| Approach Total | 4484 | 157 | 4641 | 5 hr 05 min 24 s |
| Departure | | | | |
| Atlanta | 719 | 65 | 784 | 0 hr 59 min 28 s |
| Chicago | 581 | 56 | 637 | 0 hr 59 min 34 s |
| Dallas Ft Worth | 742 | 60 | 802 | 0 hr 58 min 47 s |
| New York | 681 | 25 | 706 | 0 hr 59 min 50 s |
| Southern California | 782 | 20 | 802 | 1 hr 00 min 20 s |
| Departure Total | 3505 | 226 | 3731 | 4 hr 57 min 59 s |
| Grand Total | 7989 | 383 | 8372 | 10 hr 03 min 23 s |

sequence that they occur in the transmission cycle. That is, push-to-talk onset precedes voice onset and voice offset follows voice onset, etc. Their definitions and the process of identification are expounded upon next.

**Push-to-Talk Onset.** PTT onset was defined as the first transition from static signaling that the mic had been keyed and the voice stream was imminent. As shown in Figure 1, PTT onset occurred at 2 min 13 s 226 ms into the tape. The dashed vertical line identifies the point of PTT onset.

**Voice Onset.** Voice onset was defined as the start of the first word in a transmission. By listening to and advancing the transmission starting point along the timeline from PTT onset until the first word was affected aided us in determining the point of voice onset. The next example (Figure 2) shows that the audio signal began to resemble human speech at 2 min 13 s 357 ms, and that point was recorded as voice onset. Figure 3 shows that voice onset usually corresponded to a clear step magnitude increase of frequencies up to 4000 Hz.

**Voice Offset.** Voice offset was defined as the end of the last word in a transmission. Once again, by listening to and delaying the transmission end point along the timeline until the final word was affected aided us in determining the point of voice offset. Figure 4 shows an example of the earliest point that the last word was unaffected (no cutoff detected). In this case it occurred at 2 min 18s 630 ms. Continuation of the signal beyond the point of voice offset was due to electronic effects from the transmitter, as evidenced by the spectral view.


**Figure 1.** Magnification of PTT onset


**Figure 2.** Magnification of voice onset

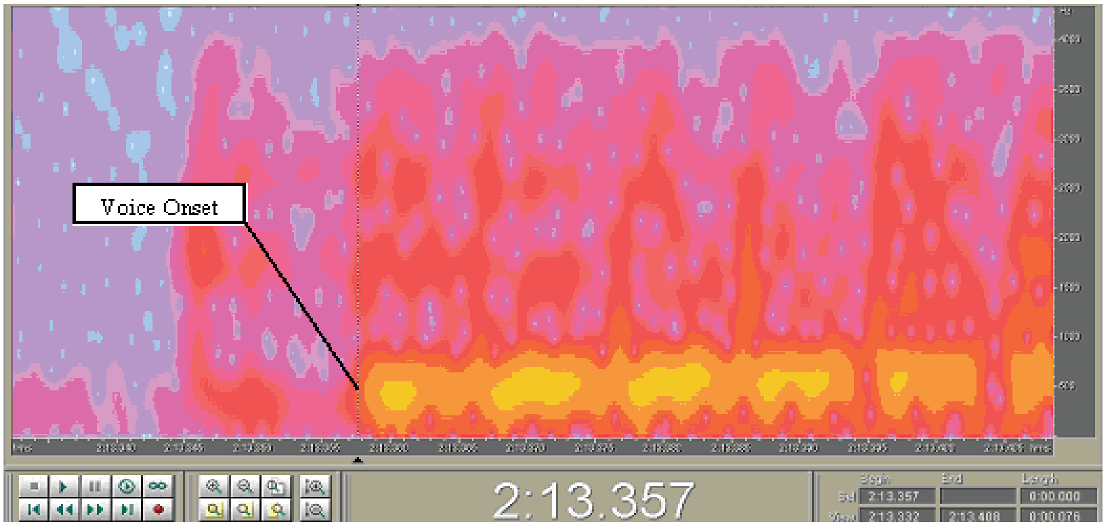


**Figure 3.** Spectral display of voice onset

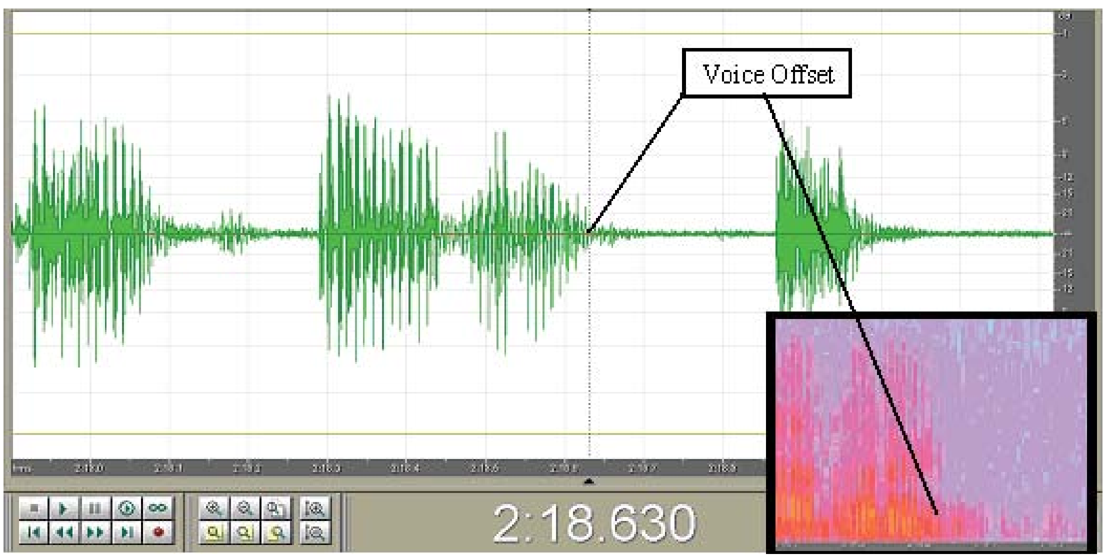


**Figure 4.** Waveform and spectral view of voice offset

PTT release was defined as the start of the microphone (mic) pop-back that occurred when the PTT button was released following the offset of the voice transmission. For most controller transmissions, like the one presented in Figure 5, this pop was very noticeable.

**Push-to-Talk Settle.** PTT settle was defined as the first return to a low signal condition following the release of the mic switch. The low signal condition starts when the transmission has decayed to less than 90% of its peak value. In this low signal condition, transmissions from other sources are not blocked. As shown in the example in Figure 6, PTT settle occurred at 2 min 18 s 990 ms.

**Accuracy in the Extraction of the Voice Communications Data Points**

To ensure the accuracy and consistency of the data, only the pilot-SME extracted the voice communications data points. To evaluate the accuracy of the communications data points, data generated by the pilot-SME was compared with a subset of the data coded by the third SME. Some variability was expected in estimating the point of voice onset and voice offset as well as the PTT measures for pilot as compared with controller transmissions. The most obvious sources of variability included 1) differences in cockpit background noise, 2) ambient noise conditions at the TRACON facilities, and 3) differences in the air-ground voice communications systems.

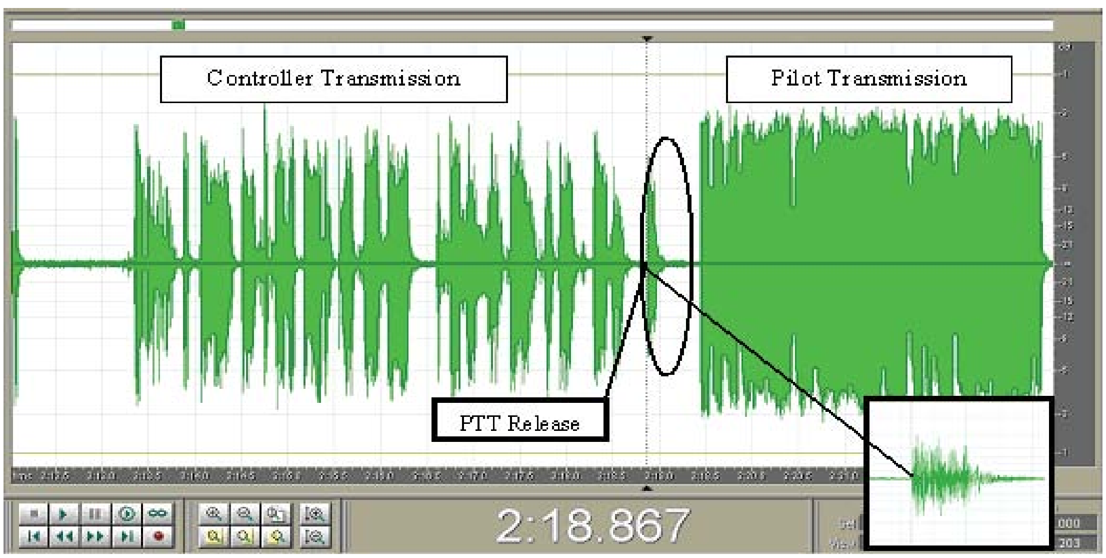


**Figure 5.** An example of PTT release with magnification

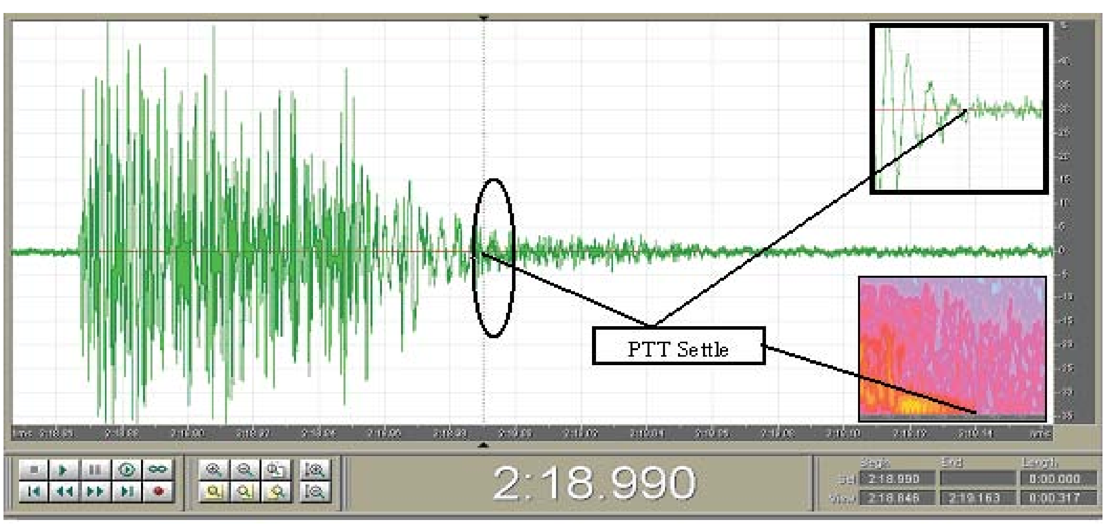


**Figure 6.** Example of PTT settle with magnification

Four samples of 25 transmissions were randomly selected for waveform analysis. The voice communications data points were independently extracted by each SME and used to compute an absolute difference score for each pair of data points. For example, if both SMEs encoded the PTT onset for transmission 1 as occurring at 937 ms into the tape, then PTT onset $_{T1}$ = |0|. However, if one SME had encoded PTT onset $_{T1}$ as occurring at 937 ms and the other SME encoded it at 941 ms, then PTT onset $_{T1}$ = |4|. The absolute difference scores were used to determine the percent agreement.

Presented in Table 2 is a frequency distribution of the absolute differences in values for each type of communications data point. For example, it shows that for the extraction of PTT onset, the SMEs had a 0 ms difference for 23.5% of the controller and 57.1% of the pilot transmissions. There was a 1-5 ms difference for an additional 60.8% of the controller and 40.8% of the pilot PTT onset times. Taken together, the data show that the SMEs were within 0 ms to 5 ms of each other in determining PTT onset time for 84.3% of the controller and 97.9% of the pilot transmissions. The largest disparities in agreement occurred for voice onset and voice offset times – that is not surprising given the added factor of noise present on the flight deck and background noise at the air traffic control facility.

Of the 400 possible data points, seven were left blank (indicating that values could not be extracted from the waveform) and four had extreme absolute differences |127|, |153|, |165|, and |290| ms.

A closer re-evaluation of these differences revealed that one of the SMEs did not include the word "and" (127 ms) as part of the transmission, "and Delta twelve fifty heavy runway two seven left," whereas the other SME did. Also, for that same transmission, one SME excluded the word "left" as part of the waveform (290 ms). The other two extreme absolute differences were attributed to the exclusion of the final phonemes in two transmissions by one of the SMEs ("en" in the word "seven" and "isk" from the word "six"). Because extreme values are known to skew results, they were excluded from the computation of the accuracy estimates summarized in Table 3. As expected, voice onset and voice offset times were more variable than estimates of PTT onset and PTT release. Even so, the largest absolute mean difference of |22.86| ms that occurred for determining the voice onset time

**Table 2.** Percentage Agreement in the SMEs' Absolute Difference Accuracy Estimates

| Absolute Difference (milliseconds) | Pilot and Controller Voice Communications Time Extractions | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | PTT Onset | | Voice Onset | | Voice Offset | | PTT Release | | PTT Settle | |
| | C* | P* | C | P | C | P | C | P | C | P |
| 0 | 23.5% | 57.1% | 21.6% | 6.1% | 2.0% | 6.1% | 33.3% | 16.3% | 23.5% | 14.3% |
| 1-5 | 60.8% | 40.8% | 43.1% | 28.6% | 43.1% | 30.6% | 62.7% | 53.1% | 45.1% | 59.2% |
| 6-10 | 2.0% | | 7.8% | 12.2% | 7.8% | 8.2% | 2.0% | 14.3% | 13.7% | 12.2% |
| 11-15 | 2.0% | 2.0% | 7.8% | 6.1% | 19.6% | 12.2% | | 12.2% | 9.8% | 2.0% |
| 16-20 | 2.0% | | 5.9% | 4.1% | 3.9% | 12.2% | | 2.0% | 5.9% | 2.0% |
| 21-25 | | | | 4.1% | 2.0% | 4.1% | | | | 4.1% |
| 26-30 | | | | 8.2% | 5.9% | 6.1% | | | | 2.0% |
| 31-35 | | | | 4.1% | 9.8% | 6.1% | | | | |
| 36-40 | | | 5.9% | 8.2% | | 2.0% | | | | 2.0% |
| 41-45 | | | 3.9% | 2.0% | 2.0% | | | | | 2.0% |
| 46-50 | | | 2.0% | 4.1% | | | | | 2.0% | |
| 51-55 | | | | 2.0% | | 4.1% | | | | |
| 56-60 | | | | 4.1% | | 4.1% | | | | |
| 61+ | | | 2.0% | 6.1% | 3.9% | 4.1% | | | | |
| No data | 9.8% | | | | | | 2.0% | 2.0% | | |

* C indicates Controller Transmissions and P indicates Pilot Transmissions

**Table 3.** Estimated Accuracy of the Voice Communications Data Points

| | Accuracy Estimates (in milliseconds) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Controller | | | | | Pilot | | | | |
| Source | M | SD | Min | Max | N | M | SD | Min | Max | N |
| PTT Onset | 2.30 | 3.09 | 0 | 17 | 46 | 0.73 | 1.80 | 0 | 12 | 49 |
| Voice Onset | 8.78 | 13.45 | 0 | 49 | 50 | 21.86 | 22.10 | 0 | 79 | 49 |
| Voice Offset | 13.22 | 15.60 | 0 | 87 | 50 | 15.89 | 16.18 | 0 | 59 | 47 |
| PTT Release | 0.82 | 0.94 | 0 | 6 | 51 | 4.17 | 4.39 | 0 | 17 | 48 |
| PTT Settle | 5.16 | 7.89 | 0 | 48 | 51 | 6.35 | 9.51 | 0 | 43 | 49 |

in pilot transmissions still reflects a high degree of accuracy in data point extraction. The pilot-SME had set an accuracy-encoding criterion of 25 ms and, based on the presented data, that criterion was achieved.

**Dependent Measures**

Measures of Voice Communications Systems Performance. The voice communications data points, like the ones presented in Table 4, were used to compute the duration measures of voice communications system performance. The duration measures use arithmetic duration (time stamp difference) to derive their values. The duration measures for each pilot and controller transmission included a) setup delay, b) voice-streaming time, c) pause duration following voice offset, d) message propagation, e) frequency occupancy time, f) lag time, and g) number of messages per aircraft.

a) Setup delay was the momentary pause preceding voice onset. It was computed as the difference between the point of voice onset and point of PTT onset. For Transmission 1 in Table 4, the amount of silence that preceded voice onset was 12 ms (0:00.949 - 0:00.937).

b) Voice-streaming time was computed as the difference between voice offset and voice onset. Again, using Transmission 1 in Table 3, voice-streaming time was 2 s 236 ms (0:03.185 – 0:00.949).

c) Pause duration was the amount of silence following voice offset. It was computed as the difference between PTT release and voice offset. For Transmission 1, 273 ms of silence preceded the release of the push to talk switch (0:03.458 – 0:03.185).

d) Message propagation represents the minimum time for the switching mechanism to return to a resting state following release of the mic switch. During this "settling down time," the opportunity for blocking can occur. For Transmission 1, PTT settle was computed as the difference between PTT settle and PTT release, and it was 127 ms (0:03.585 – 0:03.458).

e) Frequency occupancy time was computed as the difference between PTT release and PTT onset, and it represented how long the radio frequency was in use per transmission. For Transmission 1, frequency occupancy time was 2s 521 ms (0:03.458 – 0:00.937).

f) Lag time between Transmission 1 and Transmission 2 was computed as the difference between PTT onset for Transmission 2 and PTT release for Transmission 1. Again, using the data presented in Table 1, lag time was 396 ms (0:03.854 – 0:03.458).

g) Number of transmissions per aircraft was tallied as the number of pilot and controller messages exchanged to and from a particular aircraft flight identifier.

**Disruptions to Efficient Information Transfer.** While listening to the recorded transmissions, all of the SMEs were instructed to pay particular attention to the detection of any disruption in information transfer between the controller and pilot. Specifically, they were to note the presence of any interference such as stepped-on, blocked, or clipped transmissions and record the type of interference next to the transcribed message on their coding forms. Messages that were unintelligible, as well as transmissions that required a repetition due to a lack of response or a request by the receiver (e.g., say again, who was that calling in), were also encoded as a disruption to efficient information transfer.

In most cases, blocked transmissions were easy to identify because they were announced to the controller by the spoken word "blocked." At other times, the controller told the pilot that the transmission was blocked or stepped-on, as was the case in the following examples, "I BLOCKED YOU OWNSHIP TWENTY NINE SIXTY FIVE TEN DEGREES RIGHT CONTACT APPROACH ONE ONE NINER POINT FOUR" and "OWNSHIP SIX NINETEEN YOU WERE STEPPED ON SIR DESCEND AND MAINTAIN THREE THOUSAND." In all instances, stepped-on, blocked and clipped transmissions were identified by careful examination of each waveform while listening to the message and reading from the transcript.

**Table 4.** Examples of Voice Communications Data Points

| | | | TIME STAMP (minute:second.millisecond) | | | | |
|---|---|---|---|---|---|---|---|
| **Trans #** | **Speaker** | **Message** | **PTT Onset** | **Voice Onset** | **Voice Offset** | **PTT Release** | **PTT Settle** |
| 1 | ATC | OWNSHIP SIX THIRTY FOUR DESCEND AND MAINTAIN THREE THOUSAND FIVE HUNDRED | 0:00.937 | 0:00.949 | 0:03.185 | 0:03.458 | 0:03.585 |
| 2 | OWN634 | THREE THOUSAND FIVE HUNDRED OWNSHIP SIX THIRTY FOUR | 0:03.854 | 0:03.900 | 0:05.370 | 0:05.380 | 0:05.417 |
| 3 | ATC | OWNSHIP FOURTEEN SIXTY FOUR CONTACT TOWER ONE ONE NINER POINT ONE | 0:07.095 | 0:07.198 | 0:09.760 | 0:09.986 | 0:10.105 |
| 4 | OWN464 | NINETEEN ONE FOR OWNSHIP FOUR SIXTY FOUR GOOD DAY | 0:10.628 | 0:10.900 | 0:13.430 | 0:13.500 | 0:13.535 |

**Table 5.** System Performance Parameters for Control Voice Radio Communications (Time in ms)

| | | | Percentile | | |
|---|---|---|---|---|---|
| **Source** | **Mean** | **SD** | **50** | **95** | **N** |
| ***Across Facilities and Positions*** | | | | | |
| Setup delay (ms) | 81 | 111 | 37 | 297 | 7500 |
| Voice streaming time (ms) | 2568 | 1507 | 2266 | 5418 | 7955 |
| Pause duration (ms) | 127 | 110 | 108 | 308 | 7299 |
| Frequency occupation time (ms) | 2820 | 1547 | 2512 | 5719 | 6950 |
| Message propagation (ms) | 73 | 52 | 63 | 168 | 7262 |
| Lag time (ms) | 1736 | 4183 | 531 | 8415 | 7972 |
| N transmissions per aircraft | 11 | 7 | 10 | 26 | 725 |

## RESULTS

### Measures of Voice Communications Systems Performance

Pilot and controller transmissions were aggregated for each aircraft according to TRACON Facility and air traffic control sector. Separate analyses were performed for approach and departure control. Presented in Table 5 are the overall communications system performance parameters. The values presented beneath the column labeled "Mean" are representative of an average transmission and will be used along with the information presented in Figure 7 to illustrate the time progression of a generic ATC transmission.

The setup delay (label 1) begins when the speaker depresses the mic key and ends with voice onset. Voice-streaming time (label 2) represents the amount of time used to utter the message from voice onset to voice offset. Pause duration (label 3) represents the absence of voice following the end of the utterance to mic key release. Frequency occupancy time (label 4) is air-time measured from mic key depressed to mic key released. Message propagation (label 5) can be heard as a clacking sound that follows mic key release. It is followed by a resting state, indicating that the communications system is available to either transmit or receive another transmission. Lag time is the duration of this resting state. About 11 messages will be exchanged from pilot check-in to controller handed-off.

### Approach Control

There were 334 aircraft that received air traffic control services (Atlanta TRACON = 60, Chicago TRACON = 61, Dallas Ft Worth TRACON = 85, New York TRACON = 65, Southern California TRACON = 63). In light of the statistically significant main effect of TRACON Facility [F (28,1166.05) = 21.325], Univariate Analysis of Variance (ANOVA) and the Tukey Honestly Significant Difference (HSD) statistic were used to assess the statistically significant findings. An alpha level of .05 was set for all statistical tests. Descriptive statistics are presented in Table 6.

Results from the ANOVAs revealed that pilots flying into New York TRACON's airspace and controllers working there took less time to begin talking once the mic key was depressed than pilots and controllers at any of the other TRACON facilities. Pilots and controllers at Southern California TRACON had the longest setup delays. [Setup Delay F(4,329)=38.526]. Pilots and controllers at the Dallas Ft Worth TRACON facility released the mic key faster than their colleagues at the

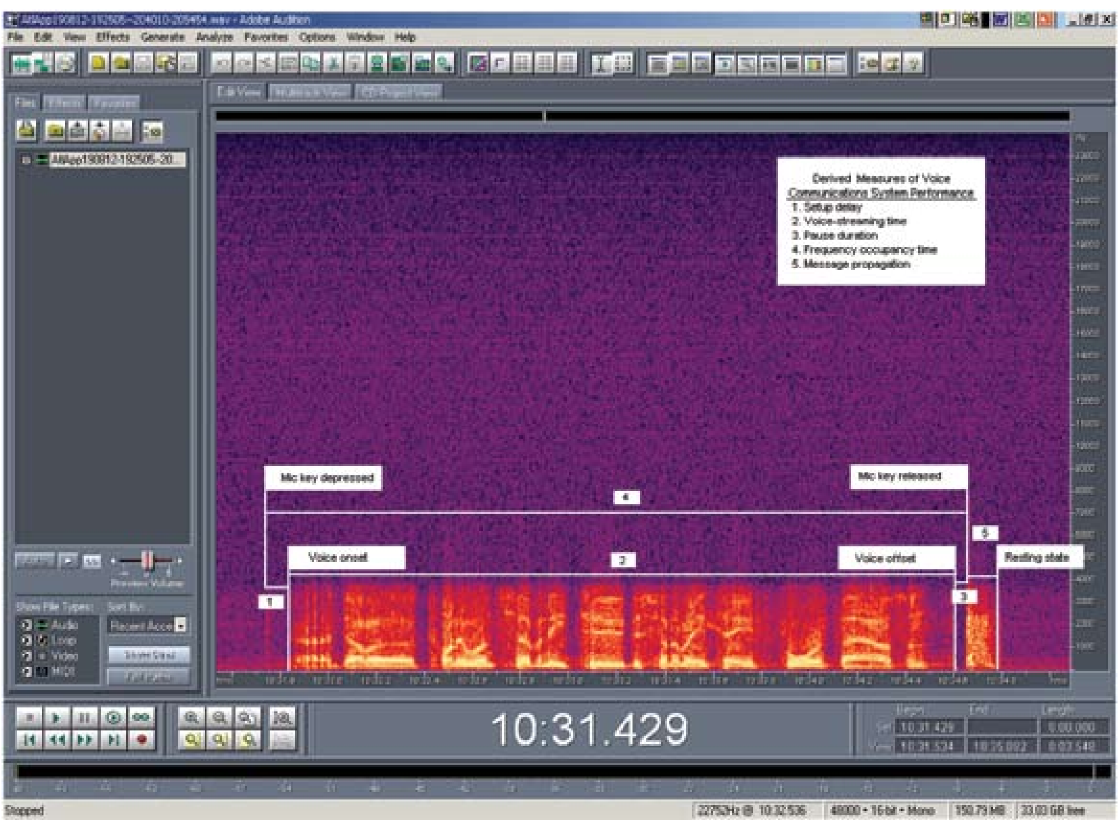


**Figure 7.** Spectral display of the derived measures of voice communications system performance

Atlanta and New York TRACONs. Their colleagues at the Southern California TRACON facility were faster than their counterparts located at the New York TRACON facility [Pause Duration F(4,329)=8.190)]. The New York TRACON had the fastest time for the switching mechanism to return to a resting state following release of the mic switch, and Dallas Ft Worth had the slowest when compared with the other TRACON facilities. [Message Propagation F(4,329)=83.991].

The ANOVA results also revealed that not only did the pilots and controllers at the Southern California TRACON spend more time transmitting individual messages, they also spent more time overall on the radio frequency than their colleagues at the other TRACON facilities sampled [Voice-streaming Time F(4,329)=31.790], [Frequency Occupancy Time F(4,329)=26.758]. Controllers and pilots at the New York TRACON spent significantly less time on frequency transmitting individual messages than pilots and controllers at the Dallas Ft Worth, Atlanta, and Southern California TRACON facilities, and they did so without a notable difference in frequency occupancy times.

Notably, both the New York and Chicago TRACON facilities experienced the least silence between successive transmissions when compared with the Dallas Ft Worth or Southern California TRACON facilities. There was less "dead-air time" at the New York TRACON facility than at the Chicago TRACON facility [Lag Time F(4,329)=11.177]. An examination of the number of messages exchanged between the pilots and controllers revealed that the New York TRACON facility transmitted more messages per aircraft than any of the other TRACON facilities, [N transmissions per aircraft F(4,329)=22.274]. The number of transmissions (per aircraft) at the Chicago and Atlanta TRACON facilities were statistically equivalent, yet greater than the number of transmissions made

**Table 6.** Approach Control Voice Communications System Performance Parameters (Time in ms)

| Source | Mean | Median | SD | Min | Max | 95% |
|---|---|---|---|---|---|---|
| Setup delay | | | | | | |
| Atlanta TRACON | 79 | 7 | 4 | 1 | 33 | 14 |
| Chicago TRACON | 95 | 8 | 5 | 3 | 28 | 19 |
| Dallas Ft Forth TRACON | 104 | 10 | 5 | 1 | 27 | 20 |
| New York TRACON | 40 | 3 | 7 | 1 | 54 | 11 |
| Southern California TRACON | 148 | 14 | 7 | 0 | 36 | 28 |
| Pause duration | | | | | | |
| Atlanta TRACON | 139 | 12 | 6 | 6 | 36 | 25 |
| Chicago TRACON | 134 | 12 | 7 | 3 | 51 | 22 |
| Dallas Ft Forth TRACON | 106 | 10 | 5 | 2 | 24 | 20 |
| New York TRACON | 160 | 15 | 5 | 8 | 32 | 27 |
| Southern California TRACON | 125 | 12 | 7 | 2 | 38 | 30 |
| Message propagation | | | | | | |
| Atlanta TRACON | 68 | 7 | 2 | 2 | 19 | 10 |
| Chicago TRACON | 72 | 7 | 3 | 3 | 21 | 11 |
| Dallas Ft Forth TRACON | 103 | 10 | 2 | 7 | 14 | 14 |
| New York TRACON | 41 | 4 | 0 | 3 | 6 | 5 |
| Southern California TRACON | 82 | 8 | 2 | 4 | 12 | 11 |
| Voice streaming time | | | | | | |
| Atlanta TRACON | 2512 | 254 | 61 | 61 | 377 | 360 |
| Chicago TRACON | 2423 | 243 | 45 | 135 | 374 | 332 |
| Dallas Ft Forth TRACON | 2491 | 246 | 57 | 160 | 421 | 382 |
| New York TRACON | 2175 | 212 | 46 | 125 | 363 | 312 |
| Southern California TRACON | 3229 | 317 | 68 | 209 | 579 | 462 |

**Table 6.** System Performance Parameters for Approach Control Voice Radio Communications (con't)

| Source | Mean | Median | SD | Min | Max | 95% |
|---|---|---|---|---|---|---|
| Frequency occupation time | | | | | | |
| Atlanta TRACON | 2745 | 275 | 64 | 78 | 414 | 397 |
| Chicago TRACON | 2641 | 263 | 48 | 173 | 402 | 350 |
| Dallas Ft Forth TRACON | 2698 | 265 | 58 | 180 | 447 | 406 |
| New York TRACON | 2515 | 239 | 71 | 99 | 616 | 371 |
| Southern California TRACON | 3536 | 349 | 70 | 220 | 613 | 486 |
| Lag time | | | | | | |
| Atlanta TRACON | 1906 | 157 | 107 | 39 | 482 | 409 |
| Chicago TRACON | 1313 | 104 | 111 | 7 | 668 | 401 |
| Dallas Ft Forth TRACON | 2177 | 147 | 195 | 28 | 987 | 655 |
| New York TRACON | 560 | 42 | 37 | 0 | 193 | 137 |
| Southern California TRACON | 2304 | 165 | 298 | 31 | 2075 | 608 |
| N transmissions per aircraft | | | | | | |
| Atlanta TRACON | 13.483 | 14 | 7 | 1 | 27 | 26 |
| Chicago TRACON | 14.852 | 14 | 8 | 1 | 30 | 29 |
| Dallas Ft Forth TRACON | 9.094 | 9 | 5 | 2 | 22 | 17 |
| New York TRACON | 20.692 | 20 | 13 | 1 | 44 | 41 |
| Southern California TRACON | 10.000 | 10 | 6 | 1 | 34 | 21 |

by pilots and controllers at the Southern California or Dallas Ft Worth TRACON facilities.

Presented in Table 7 are the frequency distributions for each of the time intervals aggregated across TRACON facilities. Column (a) shows that, for approximately 82% of the transmissions, less than 150 ms transpired from the onset of PTT to the onset of the speaker's voice (less than .025 ms = 32.8%, .025 ms - .049 ms = 16.6%, and .050 ms - .074 ms = 9.8%). As can be seen from Column (b), about 38% of the transmissions used between 1750 – 2999 ms for voice streaming. The exceedingly low values (075 – 149 ms) represent the amount of time used to produce the word "blocked."

Following voice streaming (Column c) 88.2% of the transmissions sustained pause durations less than 250 ms. Pause duration represented the amount of silence prior to the release of the PTT switch. For 92% of the transmissions, less than 150 ms was needed for the switching mechanism to return to a resting state following release of the PTT switch (Column d, Message Propagation 62.9%+29.1%). As shown by the percentages in Column (e) — 31.5% of the individually transmitted messages (18.5%+13.0%) used between 2000 – 2999 ms (between 2 to 3 seconds). The amount of time that lapsed between consecutive controller and pilot messages (that is, no land line communications computed as intervening messages, Column (f) revealed only 250 – 499 ms of silence for 25.5% and between 500 – 749 ms for 14.8% of the transmissions. Rarely (3.0%) did more than 10,000 ms transpire between successive transmissions.

**Departure Control**

There were 386 aircraft that received air traffic control services (Atlanta TRACON = 82, Chicago TRACON= 73, Dallas Ft Worth TRACON = 67, New York TRACON = 77, Southern California TRACON = 87). Once again, in light of the statistically significant main effect of TRACON Facility [F (28,1353.504) =18.566], both the Univariate Analysis of Variance (ANOVA) procedure and the Tukey Honestly Significant Difference (HSD) statistic were used to assess the statistically significant findings using an alpha level of .05 for all statistical tests. Descriptive statistics are presented in Table 8.

**Table 7.** Timing Distributions For Approach Control Voice Radio Communications

| Time Interval (milliseconds) | Set up Delay (a) | Voice Streaming (b) | Pause Duration (c) | Message Propagation (d) | Frequency Occupation (e) | Lag (f) |
|---|---|---|---|---|---|---|
| 000-074 | 64.5% | | 36.3% | 62.9% | .1% | 10.1% |
| 075-149 | 17.6% | .2% | 26.1% | 29.1% | .1% | 7.0% |
| 150-249 | 10.4% | 1.7% | 25.8% | 7.6% | .4% | 11.8% |
| 250-499 | 6.2% | 4.0% | 10.5% | .4% | 2.3% | 25.5% |
| 500-749 | .9% | 2.8% | .8% | .0% | 1.8% | 14.8% |
| 750-999 | .3% | 3.4% | .4% | | 2.2% | 9.7% |
| 1000-1249 | .0% | 5.7% | | | 4.4% | 3.5% |
| 1259-1499 | | 8.0% | | | 7.5% | 2.2% |
| 1500-1749 | | 8.6% | | | 6.9% | 1.4% |
| 1750-1999 | | 10.2% | | | 8.2% | 1.4% |
| 2000-2499 | | 16.4% | | | 18.5% | 2.1% |
| 2500-2999 | | 11.5% | | | 13.0% | 1.4% |
| 3000-3499 | | 7.7% | | | 9.8% | 1.2% |
| 3500-3999 | | 6.0% | | | 7.1% | .8% |
| 4000-4499 | | 4.3% | | | 5.5% | .6% |
| 4500-4999 | | 2.6% | | | 3.3% | .7% |
| 5000-5499 | | 1.9% | | | 2.8% | .5% |
| 5500-5999 | | 1.3% | | | 1.4% | .4% |
| 6000-9999 | | 3.6% | | | 4.6% | 2.0% |
| 10000-10000+ | | .1% | | | .1% | 3.0% |
| Total | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% |

**Table 8.** System Performance Parameters for Departure Control Voice Radio Communications (Time in milliseconds)

| Source | Mean | Median | SD | Min | Max | 95% |
|---|---|---|---|---|---|---|
| Setup delay | | | | | | |
| Atlanta TRACON | 55 | 5 | 4 | 1 | 31 | 12 |
| Chicago TRACON | 99 | 7 | 9 | 1 | 71 | 20 |
| Dallas Ft Forth TRACON | 94 | 9 | 6 | 1 | 24 | 20 |
| New York TRACON | 64 | 5 | 4 | 1 | 25 | 15 |
| Southern California TRACON | 67 | 5 | 5 | 1 | 23 | 16 |
| Pause duration | | | | | | |
| Atlanta TRACON | 146 | 13 | 7 | 5 | 47 | 28 |
| Chicago TRACON | 110 | 10 | 5 | 2 | 29 | 24 |
| Dallas Ft Forth TRACON | 119 | 11 | 6 | 0 | 31 | 23 |
| New York TRACON | 154 | 15 | 7 | 7 | 66 | 23 |
| Southern California TRACON | 104 | 10 | 4 | 2 | 29 | 17 |
| Message propagation | | | | | | |
| Atlanta TRACON | 69 | 7 | 3 | 3 | 14 | 12 |
| Chicago TRACON | 53 | 5 | 2 | 3 | 13 | 9 |
| Dallas Ft Forth TRACON | 55 | 5 | 1 | 2 | 12 | 7 |
| New York TRACON | 120 | 12 | 2 | 9 | 22 | 14 |
| Southern California TRACON | 78 | 7 | 4 | 3 | 28 | 15 |
| Voice streaming time | | | | | | |
| Atlanta TRACON | 2477 | 248 | 44 | 160 | 451 | 328 |
| Chicago TRACON | 2573 | 253 | 39 | 170 | 390 | 330 |
| Dallas Ft Forth TRACON | 2667 | 263 | 58 | 124 | 425 | 353 |
| New York TRACON | 2886 | 286 | 60 | 131 | 467 | 391 |
| Southern California TRACON | 2849 | 285 | 55 | 95 | 401 | 383 |
| Frequency occupation time | | | | | | |
| Atlanta TRACON | 2512 | 250 | 46 | 154 | 390 | 325 |
| Chicago TRACON | 2782 | 270 | 46 | 194 | 491 | 354 |
| Dallas Ft Forth TRACON | 2931 | 292 | 65 | 93 | 492 | 417 |
| New York TRACON | 3124 | 308 | 62 | 153 | 526 | 408 |
| Southern California TRACON | 3005 | 297 | 59 | 102 | 437 | 398 |

Table 8. System Performance Parameters for Departure Control Voice Radio Communications (con't)

| Source | Mean | Median | SD | Min | Max | 95% |
|---|---|---|---|---|---|---|
| Lag time | | | | | | |
| Atlanta TRACON | 2784 | 215 | 204 | 36 | 1200 | 649 |
| Chicago TRACON | 3393 | 250 | 46 | 194 | 491 | 354 |
| Dallas Ft Forth TRACON | 1755 | 116 | 181 | 07 | 1144 | 525 |
| New York TRACON | 2139 | 170 | 218 | 32 | 1700 | 450 |
| Southern California TRACON | 1462 | 96 | 124 | 14 | 674 | 398 |
| N transmissions per aircraft | | | | | | |
| Atlanta TRACON | 8.732 | 9 | 4 | 1 | 16 | 16 |
| Chicago TRACON | 7.932 | 8 | 3 | 2 | 17 | 13 |
| Dallas Ft Forth TRACON | 11.045 | 11 | 6 | 2 | 36 | 19 |
| New York TRACON | 8.805 | 9 | 4 | 1 | 22 | 18 |
| Southern California TRACON | 8.954 | 9 | 4 | 1 | 23 | 18 |

The ANOVAs revealed that pilots and controllers at the Atlanta, New York, and Southern California TRACON facilities took less time to begin talking after the mic key was depressed than pilots and controllers at either the Chicago or Dallas Ft Worth TRACON [Setup Delay $F(4,381)=8.594$]. Just as there was no reliable difference in setup delay among the Atlanta, New York, and Southern California TRACON facilities, there was no reliable difference between Chicago and Dallas Ft Worth.

Interestingly, pilots and controllers at the Atlanta and New York TRACON facilities were slower to release the mic key when finished speaking than the pilots and controllers at either the Chicago or Southern California TRACONs. Pause durations were also longer at the New York TRACON when compared with those at the Dallas Ft Worth TRACON [Pause Duration $F(4,381)=10.383$].

The Chicago TRACON had the fastest time for the switching mechanism to return to a resting state following release of the mic switch when compared with the other TRACON facilities. In contrast, the New York TRACON had the slowest switchover time when compared with the other TRACON facilities. The Dallas Ft Worth TRACON had a faster mean switchover time compared with either the Atlanta or Southern California TRACONs [Message Propagation $F(4,381)=97.565$].

The ANOVA also revealed that the pilots and controllers at the Atlanta and Chicago TRACON facilities spent less time transmitting individual messages than their colleagues at the Southern California or New York TRACON facilities. Pilots and controllers at the Dallas Ft Worth TRACON did not differ from any of the TRACONs [Voice-streaming Time $F(4,381)=9.707$]. Pilots and controllers at the Atlanta TRACON spent the least time overall on the radio frequency. The only other statistically significant difference involved the pilots and controllers at the Chicago TRACON facility — they spent less time on frequency overall when compared with their cohorts at the New York TRACON [Frequency Occupancy Time $F(4,381)=14.307$].

Notably, both the Southern California and Dallas Ft Worth TRACONs experienced the least amount of silence between successive transmissions and less than either the Atlanta or Chicago TRACONs. The New York TRACON also had less time between successive transmissions than the Chicago TRACON [Lag Time $F(4,381)=11.222$]. Interestingly, the Dallas Ft Worth TRACON had the most transmissions exchanged per aircraft [N transmissions per aircraft $F(4,381)=4.898$]. The number of transmissions per aircraft was comparable at all of the remaining TRACON facilities.

To get a sense of the communications process typical at the departure control sectors sampled, presented in Table 9 are the frequency distributions for each time interval aggregated across TRACON facilities. Column (a) shows that, for approximately 85% of the transmissions, less than 150 ms transpired from the onset of PTT to the onset of the speaker's voice (.024 ms or less = 42.9%, .025 ms - .049 ms = 17.5%, and .050 ms - .074 ms = 8.4%).

**Table 9.** Timing Distributions For Departure Control Voice Radio Communications

| Time Interval (milliseconds) | Set up Delay (a) | Voice Streaming (b) | Pause Duration (c) | Message Propagation (d) | Frequency Occupation (e) | Lag (f) |
|---|---|---|---|---|---|---|
| 000-074 | 71.0% | .1% | 38.0% | 51.8% | .0% | 4.6% |
| 075-149 | 14.1% | .1% | 31.0% | 44.0% | .2% | 5.0% |
| 150-224 | 8.3% | 1.2% | 21.4% | 3.3% | .2% | 8.8% |
| 250-499 | 5.5% | 2.6% | 8.6% | .9% | 2.1% | 20.7% |
| 500-749 | .6% | 1.2% | .7% | .1% | 1.5% | 17.9% |
| 750-999 | .3% | 1.7% | .3% | | 1.6% | 11.6% |
| 1000-1249 | .1% | 3.9% | | | 2.8% | 4.7% |
| 1259-1499 | .0% | 7.1% | | | 4.6% | 3.4% |
| 1500-1749 | | 7.7% | | | 8.1% | 2.6% |
| 1750-1999 | | 8.8% | | | 7.4% | 2.0% |
| 2000-2499 | | 18.1% | | | 17.9% | 2.3% |
| 2500-2999 | | 13.3% | | | 14.7% | 2.0% |
| 3000-3499 | | 10.3% | | | 11.0% | 1.2% |
| 3500-3999 | | 8.3% | | | 8.6% | 1.4% |
| 4000-4499 | | 5.1% | | | 6.3% | 1.1% |
| 4500-4999 | | 3.3% | | | 4.3% | .9% |
| 5000-5499 | | 2.9% | | | 3.2% | .6% |
| 5500-5999 | | 1.9% | | | 2.0% | .5% |
| 6000-9999 | | 2.4% | | | 3.5% | 3.3% |
| 10000-10000+ | | .1% | | | .1% | 5.5% |
| Total | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% |

Looking at Column (b), about 42% of the transmissions used between 2000 – 3499 ms for voice streaming. The exceptionally short values for voice streaming (000-149 ms) represent the amount of time used to produce the word "blocked."

Following the voice stream measure, Column c shows that about 90% of the transmissions had pause durations under 250 ms. For 95.8% of the transmissions, less than 150 ms was needed for the switching mechanism to return to a resting state [see Column (d), Message Propagation 51.8%+44.0%]. Column (e) shows that 43.6% of the individual pilot and controller messages lasted between 2000-3499 ms (approx 2 to 3.5 seconds). Finally, Column (f) shows that the time elapsed between their consecutive transmissions was 250 – 499 ms of silence for 20.7% and 500 – 749 ms for another 17.9% of their transmissions.

**Disruptions to Efficient Information Transfer**

The final set of analyses examined the data for the presence of blocked, stepped-on, clipped, and other types of transmissions that could contribute to, or result in, disruptions to efficient information transfer. Table 10 shows that 178 out of the original 7989 transmissions (2.2%) either created (1.16%) or had the potential to create (1.06%) a disruption to efficient information transfer. In many cases, these disruptions led to the repetition of the original message by the speaker (29.21%) or a request for a retransmission of that message by the receiver (23.03%). Consequently, an additional 140 messages were exchanged between pilots and controllers to resolve problems in information transfer. A comparison between aircraft with and without disruptions revealed that when a disruption was present, 14.54 messages were transmitted compared with an average of 9.90 messages when no disruption was present [$t(735)=-7.257$], $p<.01$.

**Table 10.** Types of Disruptions Presented by Their Outcome on Communications

| Source | Outcome on Controller and Pilot Communications: Speaker Repeated the Transmission | Receiver Requested a Repeat of the Transmission | Continuation of Routine Communications | Total |
|---|---|---|---|---|
| Controller-detected blocked message | 3 | 3 | 1 | 7 |
| Voice saying "blocked" | 15 | 1 | 1 | 17 |
| Heterodyne tone indicating blocked | 2 | 0 | 0 | 2 |
| No response to message | 14 | 0 | 0 | 14 |
| Controller-detected stepped-on | 3 | 3 | 0 | 6 |
| First part of the message was stepped-on | 3 | 1 | 16 | 20 |
| End of the message was stepped-on | 0 | 1 | 10 | 11 |
| First part of the message was clipped | 1 | 1 | 5 | 7 |
| End of the message was clipped | 1 | 0 | 23 | 24 |
| Message reception (static, interference) | 7 | 30 | 16 | 53 |
| Mic click response to ATC messages | 3 | 1 | 13 | 17 |
| Total | 52 | 41 | 85 | 178 |

Once again looking at Table 10, the most troubling types of disruptions involved blocked transmissions (14.61%) and transmissions that were not acknowledged (7.86%). When transmissions were completely blocked, an audible alarm (17 with the spoken word "blocked" and 2 heterodyning) typically alerted the controller (Atlanta 5, Chicago 4, Dallas Ft Worth 1, New York 5, Southern California 4). In 94.74% of those instances, the controller repeated the transmission (89.47%) or requested a repeat from the pilot (5.26%). Notably, even in the absence of an aural alert, the controller took similar action — in 85.71% of those instances the controller either repeated or requested a repeat of that transmission from the pilot (Atlanta 2, Dallas Ft Worth 3, New York 1, Southern California 1). For example, in the following transmission, the pilot is attempting initial contact with approach control, "THREE OH EIGHT SEVEN THOUSAND YANKEE." The controller responds with, "I BLOCKED YOU, I KNOW WHO YOU ARE, I'LL BE RIGHT BACK."

Somewhat troublesome was the lack of a pilot acknowledgment to some controller instructions. Of the 14 transmissions that were not acknowledged, 11 originated with the controller and all were rebroadcast (Atlanta 6, Chicago 1, Dallas Ft Worth 1, New York 1, Southern California 2). It is unclear why the pilots did not respond to these controller-generated messages the first time they were transmitted. In contrast, pilot repetitions involved attempts to initiate radar contact with controllers.

No alerting system was detected for stepped-on (20.79%) or clipped (20.79%) transmissions through waveform analysis. What makes this finding interesting is that when controllers detected that a message was stepped-on, that message was rebroadcast in all cases (Atlanta 1, Dallas Ft Worth 3, New York 1, Southern California 1); however, when either the beginning (Dallas Ft Worth 4, New York 12, Southern California 4) or end of a message (Dallas Ft Worth 5, New York 6) was partially stepped-on only 16.13% of them were retransmitted (5 of the 31 partial messages). Not surprisingly, only 10.34% of the clipped transmissions were retransmitted (3 out of 31; Atlanta 6, Chicago 8, Dallas Ft Worth 4, New York 7, Southern California 6).

The findings presented in Table 10 also revealed that the largest contributor to information transfer problems involved message reception — 29.78% of the transmissions had static, background noise, or some other type of interference present (Atlanta 12, Chicago 9, Dallas Ft Worth 5, New York 10, Southern California 17). Of these 53 transmissions, 69.81% were rebroadcast. When the intelligibility of the messages was a problem, as it was in 18 transmissions, only two were rebroadcast. Given the

habitual and repetitive nature of ATC communications and its constrained phraseology, controllers and pilots have the ability to understand distorted, and otherwise partially unintelligible transmissions. When other factors were involved, as was the case for 35 messages, those messages were always repeated. For example, pilots might repeat their initial contact message to departure control if not acknowledged promptly by the controller. The lack of an immediate response to the first pilot call by the controller could be due to many factors. Likewise, if a controller did not receive a timely read back to a control instruction or clearance acknowledgment, that message would be repeated.

There were 17 occasions where pilots acknowledged controllers' messages with a mic click (Atlanta 4, Chicago 5, Dallas Ft Worth 2, New York 3, Southern California 3). Of these non-verbal acknowledgments, the controller retransmitted the original message 23.53% of the time, apparently expecting a verbal confirmation from the pilot. For example, the controller expected a pilot readback of the following clearance instruction, "OWNSHIP ELEVEN THIRTY SIX ONE SEVENTY AIRSPEED AND THEN MAINTAIN FOUR THOUSAND" and not a mic click. Accordingly, the controller reissued the instruction and the pilot read back, "ONE SEVENTY THEN FOUR THOUSAND OWNSHIP ELEVEN THIRTY SIX." In some cases, a verbal acknowledgment was not deemed necessary — for example, a double click was given in response to the controller's transmission, "OWNSHIP TWO NINETY SIX ATLANTA RADAR CONTACT."

**Table 11.** Type of Disruption Presented by Facility and System Performance Measures (in ms)

| | Type of Disruption | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | No Disruptions | | | Clipped Transmissions | | | | | |
| | | | | Start | | | End | | |
| **Source** | **Mean** | **SD** | **N** | **Mean** | **SD** | **N** | **Mean** | **SD** | **N** |
| Setup delay | | | | | | | | | |
| Atlanta | 64 | 90 | 1494 | 32 | 01 | 2 | 115 | 120 | 4 |
| Chicago | 92 | 125 | 1461 | 42 | - | 1 | 97 | 182 | 7 |
| Dallas Ft Worth | 99 | 115 | 1487 | 09 | - | 1 | 102 | 93 | 3 |
| New York | 49 | 75 | 1990 | 02 | - | 1 | 104 | 178 | 6 |
| Southern California | 106 | 135 | 1375 | 09 | 11 | 2 | 30 | 33 | 4 |
| Pause duration | | | | | | | | | |
| Atlanta | 137 | 114 | 1494 | 51 | 01 | 2 | 13 | 13 | 4 |
| Chicago | 123 | 109 | 1461 | 27 | - | 1 | 154 | 228 | 7 |
| Dallas Ft Worth | 109 | 109 | 1487 | 93 | - | 1 | 49 | 69 | 3 |
| New York | 155 | 105 | 1990 | | - | 1 | 162 | 247 | 6 |
| Southern California | 111 | 105 | 1375 | 154 | 108 | 2 | 41 | 46 | 4 |
| Message Propagation | | | | | | | | | |
| Atlanta | 67 | 48 | 1494 | 103 | 33 | 2 | 32 | 12 | 4 |
| Chicago | 65 | 50 | 1461 | 03 | - | 1 | 81 | 34 | 7 |
| Dallas Ft Worth | 82 | 55 | 1487 | 11 | - | 1 | 32 | 14 | 3 |
| New York | 72 | 46 | 1990 | - | - | 1 | 67 | 43 | 6 |
| S. California | 81 | 61 | 1375 | 150 | 52 | 2 | 55 | 18 | 4 |

## DISCUSSION

Effective communications in the National Airspace System is an essential component of safe and efficient air travel. Communicated information can be generated from radar track data, automatic dependent surveillance broadcast, voice radio, or a data link. It can be presented as visual or auditory information. Its source can be from either a ground-based or satellite communications systems. As technological advances lead to innovations in communications systems development, those emerging systems will need to be evaluated against the existing legacy system's performance parameters. Some of those parameters include throughput measures — such as the ones presented in this report.

The major findings from the analysis of nearly 8000 individual waveforms are that communications occur quickly and with little silence occurring between transmissions. On average, there were about 13 air-ground transmissions generated for every minute sampled. Typically, once the push-to-talk switch was depressed, communications began 81 ms later. It took about 2.5 sec to generate a message, and another 127 ms lapsed before the push-to-talk switch was released. The communications system was ready to receive another transmission about 73 ms later. From the moment that the push-to-talk switch was depressed and then released, nearly 3 sec lapsed. On average, transmissions were separated by 1.75 sec of silence. In summary, approximately 70% of each minute was devoted to pilot and controller communications (39 sec communicating and 2.5 sec for the communications systems to return to a steady state). Add in the number and duration of land-line transmissions, and it is easy to determine that the current communications system is approaching saturation levels.

Potential problems can result from blocked, stepped-on, and clipped transmissions — but these are rare events. During the 603 minutes sampled, only 178 disruptions were identified, of which 93 required a retransmittal of the original message. Even so, there seems to be some type of detection system in place to identify blocked transmissions and alert the controller to their presence. Future systems developers may want to exploit this detection system and expand it to include stepped-on and clipped transmissions.

Although it is unfortunate that there was insufficient data with which to perform the needed inferential statistics to identify whether a causal relationship exists between the duration measures of the communications system performance and the types of disruptions identified, some liberty was taken. Presented in Table 11 are the system performance measures (i.e., setup delay, pause duration, message propagation) for the transmissions that experienced either no disruption or were clipped. Intuitively, it would make sense to expect that clipped transmissions at the beginning of the voice stream to have shorter setup delays than transmissions that were not disrupted. An examination of the data presented in Table 11 supports that assertion. Also, it could be assumed that when the end of a transmission is clipped there would be shorter pause durations and, in fact, the data confirm that.

The data presented in this report are but a first step in providing objective and quantifiable communications system performance metrics. Perhaps these metrics and parametric values will prove beneficial to communications systems developers and FAA personnel charged with the evaluation, certification, and deployment of the next generation of communications systems.

## REFERENCES


Federal Aviation Administration (1995a). The Next-Generation A/G Communications System MNS-137. http://ntl.bts.gov/lib/000/400/400/mns137.pdf. Accessed 25 March 2005.

Federal Aviation Administration (1995b). U.S. Department of Transportation Federal Aviation Administration Specification NAS System Specification Volume III Functional and Performance Requirements for the Ground-to-Air Element. http://nasdocs.faa.gov/nasiHTML/nas/ss1000/ss3.html. Accessed 25 March 2005.

Federal Aviation Administration (1998). Investment Analysis Report Next-Generation Air/Ground Communications System. http://www.faa.gov/asd/ia-or/pdf/nexcomiar.pdf. Accessed 25 March 2005.

Federal Aviation Administration. (July 2004). FAA Long Range Aerospace Forecasts Fiscal Years 2020, 2025 and 2030. FAA/APO-04-3. Washington DC: Federal Aviation Administration. http://apo.faa.gov/Forecast%20LongRange%2004/long04.pdf. Accessed 25 March 2005.

Federal Aviation Administration. (2005). National Airspace System Capital Investment Plan. Office of System Architecture and Investment Analysis. http://nasdocs.faa.gov/nasihtml/cip/CIP_2005.pdf. Accessed 25 March 2005.

Nadler, E., Mengert, P., DiSario, R., Sussman, E.D., Grossman, M., Spanier, G. (1993). Effects of Satellite-and-Voice-Switching-Equipment Transmissions Delays on Air Traffic Control Communications. The International Journal of Aviation Psychology. 3(4). p. 315-25.

O'Neil, K. (2005). Improving the Safety of Communications. http://www.aatl.net/publications/contran.htm. Accessed 25 March 2005

Prinzo, O.V., Britton, T.W., & Hendrix, A. (1995). Development of a Coding Form for Approach Control/Pilot Voice Communications. DOT/FAA/AM-95/15. Washington, DC: Federal Aviation Administration.[1]

Sollenberger, R.L., McAnulty, D.M., Kerns, K. (2003). The effect of voice communications latency in high density, communications-intensive airspace (DOT/FAA/CT-TN03/04). Atlantic City International Airport: Federal Aviation Administration William J. Hughes Technical Center.

[1]This publication and all Office of Aerospace Medicine technical reports are available in full-text from the Civil Aerospace Medical Institute's publications Web site: www.faa.gov/library/reports/medical/oamtechreports/index.cfm